

**MODELLING OF PARTIAL DISCHARGE  
ANALYSIS SYSTEM USING WAVELET  
TRANSFORM DENOISING TECHNIQUE**

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# **Modelling of Partial Discharge Analysis System Using Wavelet Transform Denoising Technique**

by

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## LIST OF ABBREVIATIONS

AM	Amplitude Modulation
DGA	Dissolve Gas Analysis
DSI	Discrete Spectral Interference
DWT	Discrete Wavelet Transform
CBM	Condition Based Maintenance
FM	Frequency Modulation
HFCT	High Frequency Current Transformer
HLPC	High-Performance Liquid Chromatography
HV	High Voltage
IEC	International Electrotechnical Commission
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
MSE	Mean Square Error
MV	Medium Voltage
PD	Partial Discharge
PRPD	Phase Resolved Partial Discharge
RFCT	Radio Frequency Current Transformer
SAIDI	System Average Interruption Duration Index
SURE	Stein's Unbiased Risk Estimate
SNR	Signal to Noise Ratio
TNB	Tenaga Nasional Berhad
XLPE	Cross-linked Polyethylene

## LIST OF SYMBOLS

$A$	Magnitude coefficient
$A_i$	Multiple magnitude coefficient
$c_b$	Capacitance at point B
$f_i$	Multiple frequency
$L$	Level of decomposition
$n$	Number of Samples
$Q$	Apparent charge
$v_c$	Voltage across the void
$v_f$	Propagation velocity
$v_s$	Propagation velocity in free space
$\omega_d$	Angular frequency
$\varphi$	Angle (rad.)
$\varepsilon$	Effective relative permittivity

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# **Pemodelan Sistem Analisis Pelepasan Separa Menggunakan Teknik Nyah-hingar Gelombang Diskret**

## **ABSTRAK**

Objektif kajian ini adalah untuk menghasilkan sistem analisis pelepasan separa (PD) untuk menilai penggunaannya sebagai pengukuran PD yang hadir dalam peralatan voltan tinggi. Tempoh perkhidmatan sistem penebat yang lebih lama dalam voltan tinggi menyebabkan masalah besar kepada peralatan voltan tinggi yang biasanya disebabkan oleh penuaan dan kemerosotan. Sistem penebat adalah bahagian terpenting dalam peralatan voltan tinggi untuk mengelakkan sebarang pelepasan terhadap kawasan yang terlindung. Kabel yang disebabkan oleh proses penuaan boleh mengganggu keupayaan penebat dengan betul dalam kabel kuasa. Pada prinsipnya, mekanisme penuaan membawa kepada proses PD yang menyebabkan lompong dari dalam penebat pepejal, gelembung penebat cecair, pencemaran oleh zarah pada permukaan bahan penebat, zarah terapung dalam penebat gas, aktiviti korona yang dilepaskan di sekitar elektrod dalam kegagalan gas dan mekanikal atau kerosakan bahan penebat. Kesan PD adalah, penebat terhakis, kehilangan dan peningkatan suhu dan kegagalan sistem. Pada masa kini, pengukuran PD digunakan untuk mengesan kejadian pelepasan dan pengukuran dalam talian adalah lebih dipercayai dan berkesan mendiagnosis masalah penebat berbanding ukuran luar talian. Walau bagaimanapun, pengukuran dalam talian telah menghadapi masalah gangguan semasa pengukuran di kawasan perindustrian. Oleh itu, untuk mengatasi masalah ini, sistem analisis PD yang lengkap dengan teknik nyah-hingar telah dimodelkan. Perisian LabVIEW digunakan untuk memodelkan sistem dengan teknik nyah-hingar gelombang kecil diskret (DWT). Dalam kerja ini, tahap penguraian yang berbeza dan jenis ibu wavelet dalam teknik nyah-hingar DWT telah disiasat. Prestasi nyah-hingar dinilai berdasarkan pengiraan min kesilapan persegi (MSE) dan nisbah gelombang kepada hingar (SNR). Penyelidikan dibahagikan kepada tiga fasa, seperti pengambilalihan data, proses data dan analisis data. Fasa pertama adalah pengambilalihan data yang melibatkan pemodelan PD dan gelombang hingar menggunakan persamaan matematik. Seterusnya, fasa proses data melibatkan nyah-hingar menggunakan DWT. Hasilnya dimanipulasi dengan jenis ibu wavelet yang berlainan, seperti Haar, Daubechies, Coiflet, Symlets dan Biorthogonal. Akhir sekali, analisis data adalah pengiraan MSE dan SNR gelombang nyah-hingar untuk memilih ibu wavelet terbaik dalam proses nyah-hingar. Tesis ini membandingkan gelombang PD asli dengan gelombang PD yang hingar. Proses nyah-hingar membantu mengeluarkan gelombang PD asli dari gelombang yang dipengaruhi oleh hingar. Jenis ibu wavelet yang berbeza menghasilkan pelbagai gelombang nyah-hingar. SNR dikira untuk membandingkan nilai sebelum dan selepas proses nyah-hingar. Nilai SNR yang lebih tinggi memberikan hasil nyah-hingar yang lebih baik. MSE digunakan untuk menilai keberkesanan ibu wavelet, yang merupakan nilai minima menunjukkan gelombang nyah-hingar yang baik seperti db14, coif3, sym5 dan bior5.5 untuk setiap kumpulan wavelet. Walau bagaimanapun, bior5.5 dipilih sebagai wavelet ibu terbaik kerana nilai MSE yang paling kurang. Sistem ini telah berjaya dihasilkan dan sesuai untuk digunakan sebagai alat analisis untuk sebarang isyarat PD tertentu.

# **Modelling of Partial Discharge Analysis System Using Wavelet Transform Denoising Technique**

## **ABSTRACT**

The objective of this study to develop Partial Discharge (PD) analysis system to assess its use as potential PD measurement in high voltage equipment. Longer service period of insulation system in high voltage has cause major problem to the high voltage equipment which typically due to ageing and deterioration. The insulation system is the most important part of high voltage equipment to prevent any discharge adjacent at the protected area. The cable that effected due to the aging process may interrupt the ability of insulation property in the power cable. In principle, the aging mechanism lead to the process of PD that cause by voids from inside the solid insulator, bubble in liquid insulator, contamination by particles on the surface of insulating material, floating particles in gas insulator, corona activity which is discharges around an electrode in gas and mechanical failure or damage of insulation materials. The effects of PD are, insulation erode, losses and temperature increased and immediate failure of the system. Nowadays, PD measurement is applied to detect the occurrences of discharge and online measurement is more reliable and can effectively diagnose insulation problem compared to the offline measurement. However, online measurement face problem of disturbance during industrial onsite measurement. Thus, to overcome this problem, PD analysis system that equipped with denoising technique has being created. LabVIEW software is being used to model the system with Discrete Wavelet Transform (DWT) denoising technique. In this work, different decomposition level and type of mother wavelet in DWT denoising technique were investigated. The performance of denoising result is evaluated by calculation of Mean Square Error (MSE) and Signal-to-Noise Ratio (SNR). Research is divided into three phases, which are data acquisition, data process and data analysis. The first phase is data acquisition which involved modelling of PD and noise signal using the mathematical equation. Next, data process phase involved noise rejection using wavelet transform. The result is being manipulated with different type of mother wavelet, such as Haar, Daubechies, Coiflets, Symlets and Biorthogonal. Lastly, data analysis is being calculated the MSE and SNR value of denoising signal to select the best mother wavelet in denoising process. This thesis compares the pure PD signal with noisy PD signal. Denoising processed help to extract PD signal from noisy background. Different type of mother wavelet gives various denoising signal. SNR is calculated to compare the value before and after denoising process. The higher SNR value gives better denoising result. MSE is used to evaluate the effectiveness of mother wavelet, which is the minimum value show good denoising signal such as db14, coif3, sym5 and bior5.5 for each mother wavelet. However, bior5.5 is being chosen as the best mother wavelet because of its least MSE value. The system has been successfully developed and is suitable to be used as an analysis tool for any particular PD signal.

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Distribution line is the valuable equipment in electrical system; however, their production and management cost are high, and failures almost lead to catastrophic losses. Longer service period of medium voltage (MV) power equipment has caused major problem to the electric facilities due to ageing and deterioration. In MV power equipment, several materials are used for insulation purpose such as solid, liquid, gas or even a combination of these (Hvidsten, Vandbakk, & Mauseth, 2012). The most important part of MV equipment is the insulation system to prevent any discharge adjacent the protected area (Arief, Abdul-malek, Muhamad, & Ahmad, 2015).

Cross-linked polyethylene (XLPE) is widely used in Malaysia as electrical insulation in power cables. XLPE is made up from polymeric insulation material, can be used for all voltage ranges but it is well suited to medium voltage application. The important advantage of XLPE as insulation cable is their low dielectric loss. However, the mutual capacitance of XLPE cables is also lower, thus reducing the charging currents and earth-leakage currents in networks without the rigid star-point earthing. Besides, other characteristic and advantages of XLPE are the cable have excellent electrical and physical properties, have capability of carrying large currents, ease of installation due to its light weight and lastly XLPE cable is free from height limitation and can be installed

anywhere without special height consideration (Rohani, Yii, Isa, Hassan, Mukhtaruddin, & Yusof, 2016).

XLPE has good insulating properties and had been used as underground and overhead cable insulation. However, the aging process inside the cable may deteriorate the ability of the XLPE performance. The aging process of the cable insulation may due to the effect of thermal, high electrical stress, mechanical, environment and radiation. Mostly, many aging mechanisms that due to electrical stress are Partial Discharge (PD), treeing and tracking on the surface of solid dielectric, charge injection, intrinsic breakdown and overheating from current. The effects of PD occurrences are, insulation will erode, losses and temperature increased and immediate failure. The operational lifespan of cable has expected around 20 to 30 years due to the defects from aging factor. To overcome insulation problem, scheduled electrical outages will be done to replace the defected equipment. A notice of electrical interruption will be spread through the community and people can make preparation before the supply is being interrupted. The occurrence of unexpectable outage can be minimized by controlling the factor of aging mechanism. This situation leads to understanding of PD formation.

PD is defined by International Electrotechnical Commission (IEC) standard 60270 as localized electrical discharges that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor (Lemke et al., 2008). In general PD is the consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. The duration of discharge is very short which is less than  $1\mu\text{s}$  and appear in the form of various voltage impulses and current impulse (Lemke et al., 2008). PD is small electrical sparks that occur within the insulation of medium voltage (MV) (Mulroy, Hurtado, & Badetz, 2012). Normally, PD pulse can be recognized by these characteristic; frequency, phase, number of pulse rate, pulse magnitude and

occurrence duration (Isa, 2013). When a PD pulse occurs, it has  $180^\circ$  of phase difference between two focus signals. On the other hand, number of pulse rate is higher than 10 pulses per second (Xiaojuan Jiang, Yun Jiang, 2009).

PD can be caused by several unwanted activities, such as voids within solid insulation, gas bubble in liquid insulation, contamination by particles on the surface of insulating material, floating particles in gas insulation, corona activity which is discharges around an electrode in gas and mechanical failure or damage of insulation materials. Thus, PD has been recognized as a harmful ageing process for electrical insulation system (Ardila-Rey, Martínez-Tarifa, Robles, & Rojas-Moreno, 2013). PD activity is also affected by environmental factors, including temperature, humidity, discharge area and surface condition (Khan, Wani, Malik, & Al-arainy, 2013). Corona discharge shows non-uniformity of electric field on sharp edges of the conductor in Figure 1.1 (a), while surface discharge usually takes place outside the power equipment or on interfaces of dielectric material that is shown in Figure 1.1 (b). Internal discharge occurs inside the system including treeing channel and cavity discharge that show in Figure 1.1 (c) and (d) respectively.

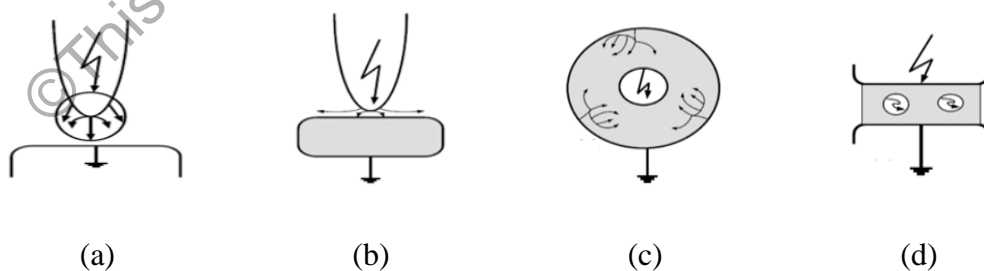


Figure 1.1: Type of PD phenomena. (a) Corona discharge (b) Surface discharge (c) Treeing channel and (d) Cavity discharge (Isa, 2013).

## 1.2 Research Motivation

Nowadays, problem arise to maximize the aging of electrical infrastructure with fewer qualified technical in-house resources and minimized cost maintenance. Due to the advances in technology, new approaches of PD analysis system can improve reliability and performance of insulation system. Continuous PD activity in insulation system may deteriorate the performance of insulation and lead to insulation failure. The process of deterioration can propagate and develop, until the insulation is unable to withstand the electrical stress and may lead to flashover. Insulation breakdown can lead to dangerous situations such as, severe damage on MV equipment and ultimately huge economic losses. Therefore, the reliability of the insulation of MV equipment should be confirmed using PD analysis.

According to Performance and Statistical Information on Electricity Supply Industry in Malaysia in year 2006 until 2013, the percentage of unscheduled interruptions increased in the year 2013. The unscheduled interruption is due to the interruption in the generation, transmission, or distribution of energy, which is not planned with short notice. Scheduled interruption is a routine interruption planned well in advance such as those scheduled for routine maintenance inspection of equipment. In Figure 1.2, the number of interruptions increase drastically from year 2006 until 2008. Then, it decreases in four years continuously. However, there are slightly increment in the year 2013 (Comission, 2013).

In Table 1.1, it shows the System Average Interruption Duration Index (SAIDI) in peninsular Malaysia from year 2008 until 2013. The statistic is categorized by different voltage level, such as low, medium and high voltage. The highest SAIDI value is in the year 2010. Among the voltage levels, MV has found to be the highest percentage. Thus, this research is more concern in MV distribution line. The focus in Table 1.2 is in MV

category, which is cable and joint had the highest percentage as compared to other equipments. Insulation problem is the reason of interruption in cable and joint of MV system. Based on this statistic, the research will be more focus on PD activity in cable and joint of MV system.

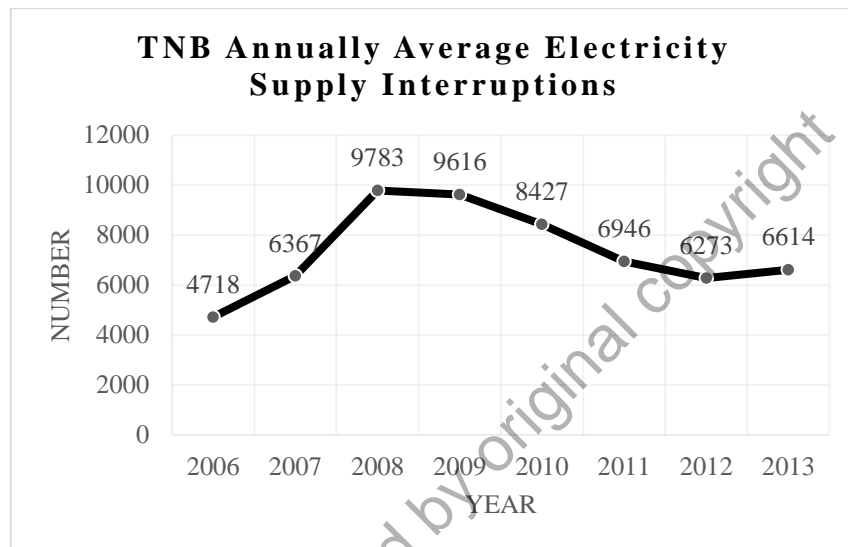


Figure 1.2: Graph of TNB annually average electricity supply interruptions.

Table 1.1: SAIDI (Minutes/Customer/Year) by Voltage Level (Comission, 2013).

Voltage Level	2008	2009	2010	2011	2012	2013
High Voltage	3.21	1.05	1.17	0.94	6.87	0.11
Medium Voltage	68.31	56.72	88.10	63.25	49.30	56.20
Low Voltage	15.79	8.30	6.98	4.93	4.29	4.04
Total	87.30	66.10	96.25	69.11	60.46	60.35

Table 1.2: Percentage of unscheduled supply interruption by type of interruptions (Comission, 2013).

Category	Medium Voltage
Cable	2418
Insulator	7
Joint	4508
Switchgears	162
Transformers	87
Others	30

Since PD usually occurs before complete breakdown, PD analysis system provides a warning to the system before catastrophic failure occurs. PD plays an important role as the indicator of the weakness of the insulation system. Data obtained through PD testing and monitoring can provide critical information on the quality of insulation and its impact on overall equipment health. PD analysis system can help predicting future performance and reliability of MV equipment, including cables, power transformer, bushings, switchgear, motors and generators. However, failures are not limited to service and aged equipment. Damage insulation also can occur from improper installation, poor design or poor workmanship during or after installation (Salathe, 2015).

Some of the important asset management drives of online measurement of MV equipments are reliability, safety of equipment, efficiency and cost of equipment. The other advantage of online PD measurement is that equipment can be tested without taking it out of service. Online measurement is also economical both in terms of time and finance and there is no extra mechanical, thermal and electrical stress on the equipment while

testing. Online PD measurement is the best way to ensure the presence of PD being analyzed efficiently. In order to get the real-time monitoring of PD, the measured data are further processed through some simulation software. With the help of Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software, the detailed mechanism of PD activity inside the insulation system can be monitored along with equivalent electrical circuit model.

PD measurement involves an analysis of materials, electric fields, arcing characteristic, pulse wave propagation and attenuation, sensor spatial sensitivity, frequency response, calibration, noise and data interpretation. Thus, excellent method needs to be chosen wisely. The comparison of online and offline PD measurement proves that online PD measurement can reliably and effectively diagnose insulation problem. Since, it is less pricey easier to perform and can be used as routine maintenance tool to monitor the progress of insulation deterioration. Consequently, online PD measurement can be established as a predictive maintenance program and maintenance costs of equipment can be reduced.

### **1.3 Research Problem**

Online PD measurement has faced problem in industrial environments such as noise in frequency measurement, signal attenuation in high frequency range and significant variation in PD activity over time (Blokhintsev, Cassidy, & Patterson, 2009), but PD measurements conducted in the laboratory are less affected by electromagnetic interference (H. Zhang, Blackburn, Phung, & Sen, 2007). Online PD measurements that picked up by the sensor is completely buried by noisy signal. Extracting the PD signal from noisy backgrounds is a major challenge for online measurement. Wavelet transform

technique is being proposed as a powerful tool to denoise the online PD signals in cables (Hashmi, 2008).

Several type of denoising techniques can be used to distinguish disturbance from the measured signal. The traditional de-noising techniques can only focus on their time or frequency domain resolution (Zhou, Zhou, & Stewart, 2006). For non-stationary and short transient PD pulses, which occur randomly, the wavelet transform is more suitable than the traditional Fourier transform as it provides information in both time and frequency domains. Digital signal processing techniques must be applied to online PD measurements to recognize PD pulses within the noisy background, which often messes the PD signal (H. Zhang et al., 2007). The ability to discriminate noise, required knowledge of both the PDs and the noise.

Noise sources may be divided into narrowband and broadband noise spectrum. The example for narrowband spectrum is discrete spectral interference (DSI) that caused by radio broadcast signal due to amplitude modulation or frequency modulation (AM/FM) radio emissions and communication networks (Altay & Kalenderli, 2010), periodical pulse shaped disturbance from power electronic equipment, and stochastic pulsed shaped from lighting or switching operations (Happe, Kranz, & Krause, 2001). Next is white Gaussian noise, which is broadband interference that caused by the measuring instrument itself.

#### **1.4 Research Questions**

The research questions for this project are:

- i. How to design PD analysis system in LabVIEW software with noise eliminations due to its disadvantage of online measurement?

- ii. How to evaluate the performance of denoising process in the LabVIEW software?

## 1.5 Objectives

The objectives for this project are:

- i. To develop partial discharge analysis system using Discrete Wavelet Transform (DWT) denoising technique.
- ii. To evaluate the performance of partial discharge analysis system based on Mean Square Error (MSE).
- iii. To evaluate the performance of partial discharge analysis system based on Signal-to-Noise Ratio (SNR).

## 1.6 Scopes

The scopes for this project are:

- i. This research is focus on online PD analysis system.
- ii. PD is being modelled using mathematical equation that represent PD signal as damped oscillatory pulse. White noise and discrete spectral interference are simulated as an environmental noise.
- iii. Wavelet transform technique is being used for denoising process. Five type of wavelet families are being used such as Haar, Daubechies, Coiflets, Symlets and Biorthogonal.
- iv. The interfaces of PD analysis and noise removing are designed using LabVIEW software.
- v. The results are being compared based on calculation of MSE and SNR.

## 1.7 Dissertation Organization

This thesis consists of five chapters that had been arranged systematically. Initially, Chapter 1 explains the purpose and background of the study. The contents of this chapter are project background, research motivation, research problem, research questions, objectives and scopes as limitations of this project.

Chapter 2 discusses about the literature research from previous work that related to this project. This chapter is reviewed about basic concept of PD, PD detection system and measurement system. Electrical detection method is being used by using Rogowski coil as PD sensor. Besides, denoising technique and advantage of using LabVIEW software also had been explained in this chapter.

Chapter 3 presents the methodology used for this project. The flowchart is provided to explain the project development. This project is divided into three group, such as data acquisition, data process and data analysis. LabVIEW software is being used in simulation work to modelled PD signal, noise interference and build the interface of PD analysis.

Chapter 4 contain overall result of this project. The results show the denoising result for five different mother wavelets. The denoising signal will be evaluated by calculating MSE and SNR. Good performance of denoising signal give the least value of MSE and the highest value of SNR.

The final chapter is Chapter 5 that will conclude all the findings of this project. The achievement of objectives is being explained in conclusion section. The result of this project proves the hypothesis regarding the denoising processed. The improvement is being suggested for future work.